THE DETERMINATION OF THE OPTIMUM LEVEL OF MECHANIZATION IN THE SELECTION OF MATERIALS HANDLING EQUIPMENT

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IN THE SELECTION OF MATERIALS HANDLING EQUIPMENT

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SUMMARY

The problem considered in this study is the way to determine the appropriate degree of mechanization of the materials handling equipment, and accordingly how to select the proper piece of equipment. The following are the steps taken:

1. Defining ten levels of mechanization of materials handling equipment, starting with manual handling, and ending with fully automated system equipment.

2. Developing a method of selecting the appropriate level of mechanization for a given situation.

3. Developing a method for selecting the appropriate type of equipment for the handling activity. The alternatives are evaluated according to both economic and intangible factors.

GLOSSARY OF TERMS

AAOC	:	Adjusted Annual Operating Cost
ADINV	:	Additional Capital Investment
AOC	:	Annual Operating Cost
ARR	:	Adjusted Rate of Return
AS	:	Annual Saving
CRF	:	Capital Recovery Factor
EQAC	:	Equivalent Annual Cost
F	:	Final Worth
i	:	Interest Rate
I	:	Minimum Acceptable Rate of Return
INV	:	Investment
n	:	Service Life
NADINV	:	New Additional Investment
NAS	:	New Annual Saving
NCRF	:	New Capital Recovery Factor
P	:	Present Worth
RR	:	Rate of Return
SS	:	Standard Service Life

CHAPTER I

INTRODUCTION

The role of materials handling equipment in industry is very pronounced, since the handling of materials, whether raw, semifinished, or finished is found in every industry. The cost of handling, as a percentage of the production cost, ranges from 10 per cent to as much as 90 per cent, which may help to explain the importance of materials handling.

Handling as well as production activities can range widely from manual to very highly automated systems. The extent of mechanization depends upon many factors such as the nature of the material being handled, the quantity being handled, resources available, psychological effects, and the like.

It is well known that the great progress in mass production is due to the use of mechanized equipment. Yet it should be emphasized that mechanization for the sake of mechanization itself may be uneconomic, and the level or degree of mechanization should be increased only when it is appropriate.

The objective of this research is to develop a method that will help determine the proper level of mechanization of materials handling equipment for a certain activity. A method for selecting the appropriate piece of equipment, based on this level of mechanization is developed.

CHAPTER II

LITERATURE SURVEY

Much has been written about materials handling equipment, and also about mechanization and automation. However, not much attention has been given to the mechanization of materials handling activities.

Professor James R. Bright (3) has developed 17 levels of mechanization for production activities. These levels are:

1. Hand
2. Hand Tool
3. Powered Hand Tool
4. Power Tool,Hand Control
5. Power Tool, Fixed Cycle
6. Power Tool, Program Control
7. Power Tool System, Remote Control
8. Actuation by Introduction of Workpiece
9. Measurement of a Characteristic
10. Signaling Selected Values
11. Recording Performance
12. Changing Speed, Position, or Direction According to Measurement
13. Segregating or Rejecting According to Measurement
14. Identifying and Selecting Appropriate Action
15. Correcting Performance after Operating

16. Correcting Performance While Operating

17. Anticipating Required Performances and Adjusting Accordingly

Table 1 shows the 17 levels of mechanization and their relationship to power and control sources.

Bright emphasizes that mechanization has at least two dimensions: Level and Span. By span is meant the extent to which the series of production activities is embraced by mechanization.

Bright has developed the "Mechanization Profile" to record these dimensions for a specific process. If the levels of mechanization are arranged as shown in Figure 1 and the levels of each operation in a manufacturing sequence are plotted, a chart results which portrays, roughly, the character of mechanization of the system. Span and level stand out clearly.

The advantages of mechanization profiles are listed by Bright as follows.*

> 1- Making such a profile is a great aid to understanding. The step-by-step examination of each operation, the consideration of the level and penetration of mechanization gives one thorough appreciation of the mechanization accomplishment. It puts the "automatic factory" into better perspective.
>
> 2- Profiles of alternative production systems enable sound comparisons and yield better understanding of the essential differences between them.
>
> 3- The profiles reveal gaps and discrepancies in mechanization along the production line rather than dramatically and thus encourages consideration of improvement.

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*James R. Bright, *Automation and Management*, p. 49.

Table 1. Seventeen Levels of Mechanization and their Relationship to Power and Control Sources

(From James R. Bright, *Automation and Management*)

Initiating Control Source	Type of Machine Response		Power Source		LEVEL OF MECHANIZATION
From a variable in the environment	Responds with action	Modifies own action over a wide range of variation	Mechanical (Nonmanual)	17	Anticipates action required and adjusts to it.
				16	Corrects performance while operating.
				15	Corrects performance after operating.
		Selects from a limited range of possible pre-fixed actions		14	Identifies and selects appropriate set of actions.
				13	Segregates or rejects according to measurement.
				12	Changes speed, position, direction according to measurement signal.
	Responds with signal			11	Records performance.
				10	Signals preselected values of measurement. (Includes error detection)
				9	Measures characteristic of work.
From a control mechanism that directs a predetermined pattern of action	Fixed within the machine			8	Actuated by introduction of work piece or material.
				7	Power Tool System, Remote Controlled
				6	Power Tool, Program Control (sequence of fixed functions).
				5	Power Tool, Fixed Cycle (single function).
From man	Variable			4	Power Tool, Hand Control.
				3	Powered Hand Tool.
			Manual	2	Hand Tool.
				1	Hand.

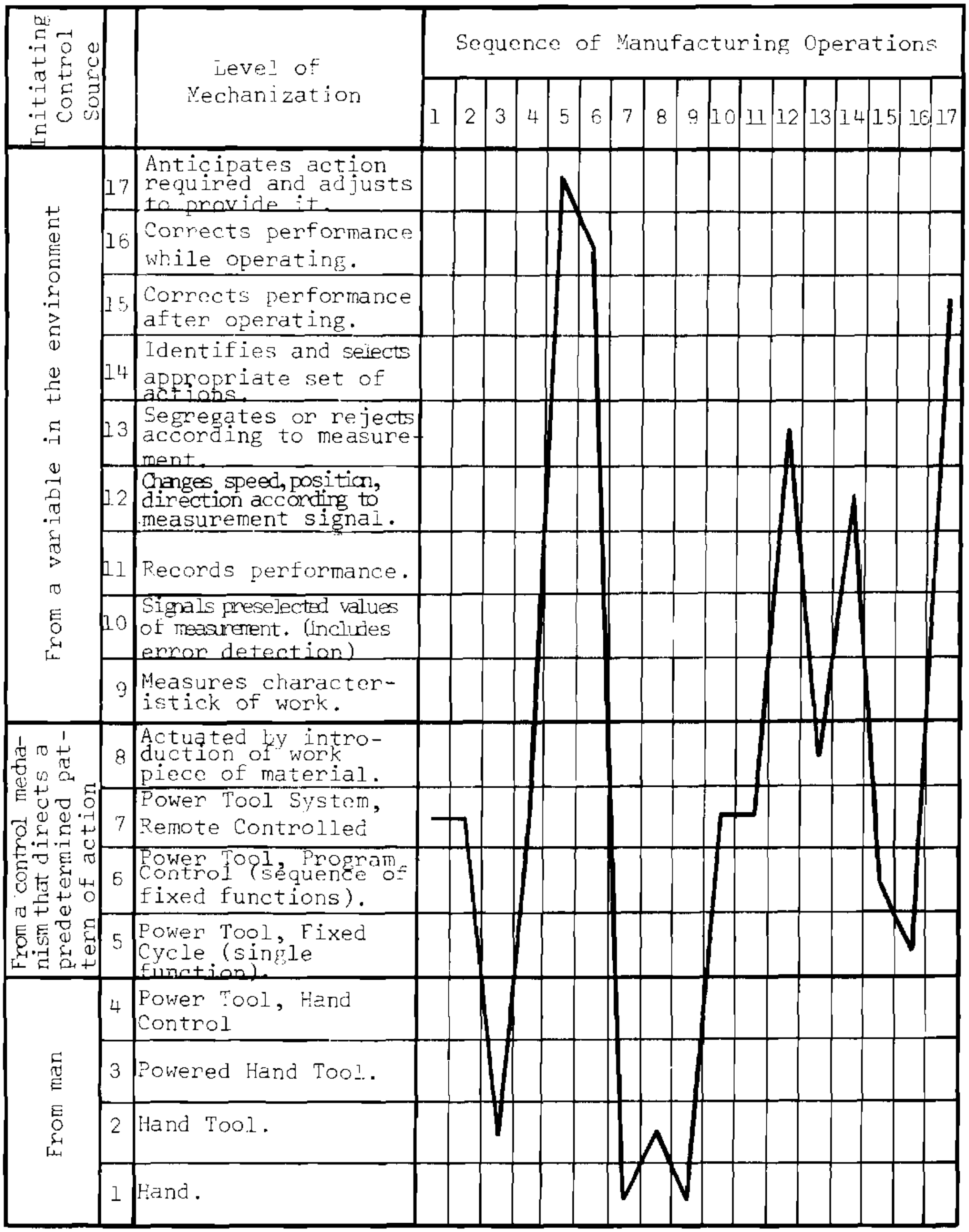

Figure 1. Example of a Mechanization Profile.

(Adapted from James R. Bright, *Automation and Management.*)

4- Through this profile technique, one can examine in detail the difference between one actual level of mechanization and the theoretically desired one. Important gaps are highlighted. The executive or engineer can then consider whether the expense and time being spent to raise the level of mechanization for a given operation seem to be reasonable. Such studies also suggest the question as to whether this effect might be directed elsewhere.

5- Accomplishments in different plants of a firm (or even of competitors) can be compared.

V. L. Lossiyevskii and L. G. Pliskin have defined two measures of automation (or mechanization), namely level, and extent. They suggested 20 levels of automation. These levels are:*

1- Manual performance of the operation (transfer, packing, visual, aural, and other checks of the process or product).

2- Manual performance of an operation using power operated auxiliaries (shovel, spanner, manipulator).

3- Manual performance of an operation using power operated auxiliaries (drill, manually operated trolley).

4- Local manual control of a power-operated device (control of a lifting crane, press control).

5- Manual remote control of a power-operated device (e.g. press button control).

6- Automatic repetition of a fixed cycle for the performance of a single operation (conveyor, feeder, doser).

7- Automatic check on the parameters of a process with the help of indicating and print-out devices requiring manual control of the process.

8- Signaling, automatic protection, blocking.

9- Automatic start and stop of the equipment in a working process determined by the presence of the product.

10- Automatic repetition of a fixed cycle, for the sequential performance of a series of operations.

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*V. L. Lossiyevskii and L. G. Pliskin, *Automation of Continuous Production Processes*, p. 9-10.

11- Automatic registration and counting of the output of a technical device.

12- Automatic control of the parameters of a process, of the working conditions of a machine, with variation of these parameters, either from previously given values, or according to a program.

13- Multipoint check on the parameters of a process, with periodical coupling to data transmitters.

14- Automatic control of the parameters of a process with automatic correction of the regulation of data transmitters by other regulations with multi-impulse operation, multi-point regulation.

15- Automatic check, with continuous analysis of the composition and quality of complex products.

16- Automatic check of the compounded parameters of a process (e.g. efficiency) with the help of calculation solution techniques.

17- Automatic centralization of the registration of the progress of a technical process with the help of techniques used on computers.

18- Automatic control of the work of the subject, with automatic correctors for machines carrying out the production process, with automatic search for the optimum working conditions for the subject.

19- Automatic start and stop of a process according to a given program.

20- Automatic self adjusting control of a process, keeping the process in step with changes in the optimum working conditions as related to changes in the internal and external influences felt during the run of the process.

The levels of mechanization given by Bright and those developed by Lossiyevskii and Pliskin are similar, to a certain extent. However, the degrees suggested by Bright are more logical are better defined.

The degrees of mechanization developed by Bright, and those developed by Lossiyevskii and Pliskin may be too sophisticated for materials handling equipment. Therefore, ten levels are developed in

Chapter III, adapted from those previously listed.

Lossiyevskii and Pliskin have developed a diagram similar to Bright's "Mechanization Profile." It consists of a rectangular diagram (see Figure 2), on the ordinate of which lie the levels of mechanization and on the abscissa are placed the designations of the production operations in sequential order corresponding to the progress of the manufacturing process.

The main difference between this diagram and Bright's mechanization profile, is that Bright considered a single profile for a manufacturing process while Lossiyevskii and Pliskin considered different mechanization profiles for the same process. These profiles may be achieved according to the desired sophistication of the system.

Figure 2 shows three possible mechanization profiles. Each profile represents a stage of mechanization for the whole process. Clearly stage 3 is more sophisticated than stage 2, which in turn is more sophisticated than stage 1.

Lossiyevskii and Pliskin assume that when changing from an especially low level of mechanization to a higher level, the cost will be lowered significantly. As the level of mechanization is increased, the lowering of the cost will be less perceptible. Finally, when an excessively high level of automation is applied, the cost may increase as a result of the increase in capital investment and operating expenses on the automatic machinery. Figure 3 shows the cost per piece versus the levels of mechanization. The degree of mechanization which corresponds approximately to the point of inflection may be considered to be the optimum.

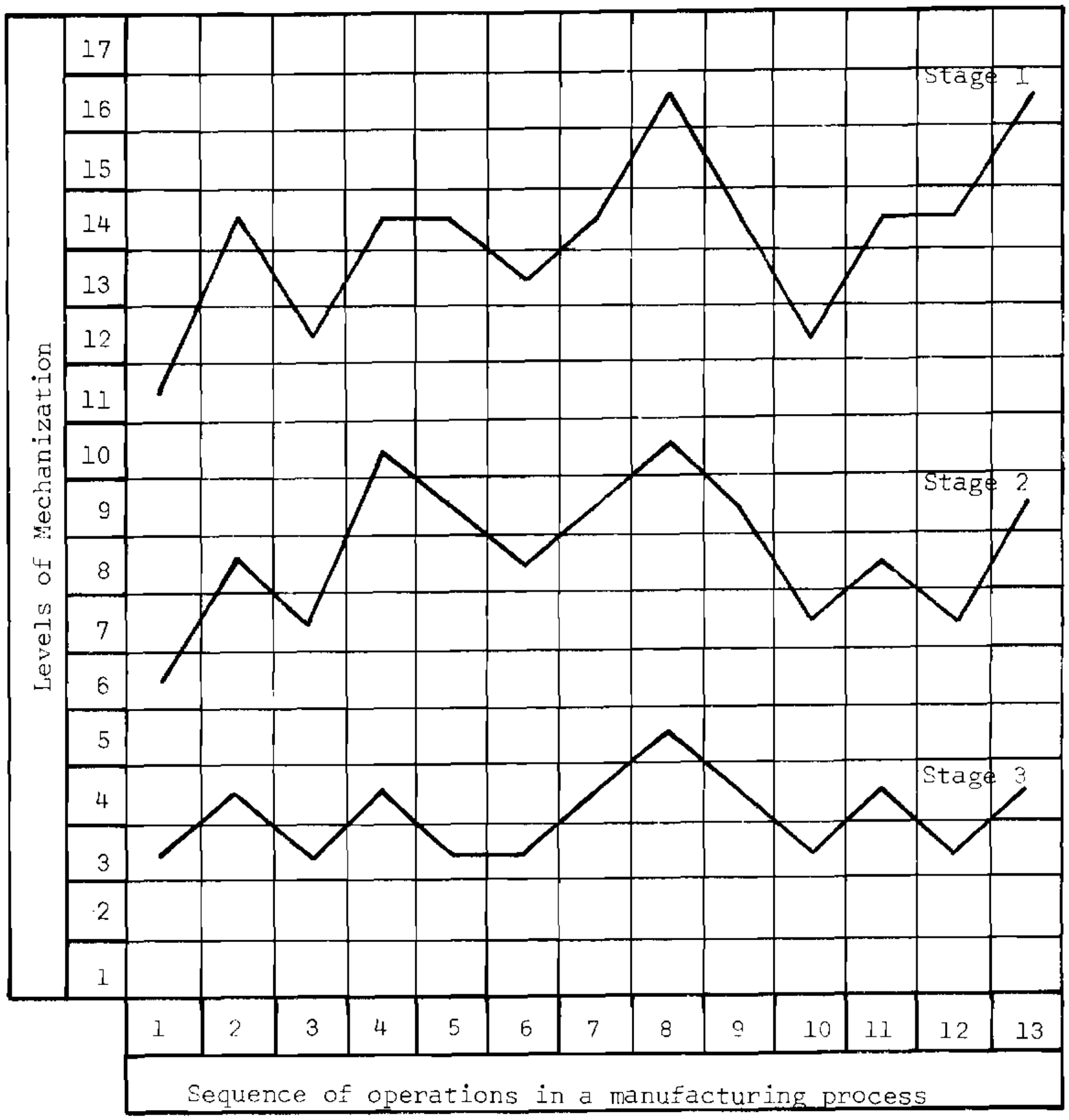

Figure 2. Different Stages of Mechanization

(Adapted from V. L. Lossiyevskii and L. G. Pliskin, *Automation of Continuous Production Processes.*)

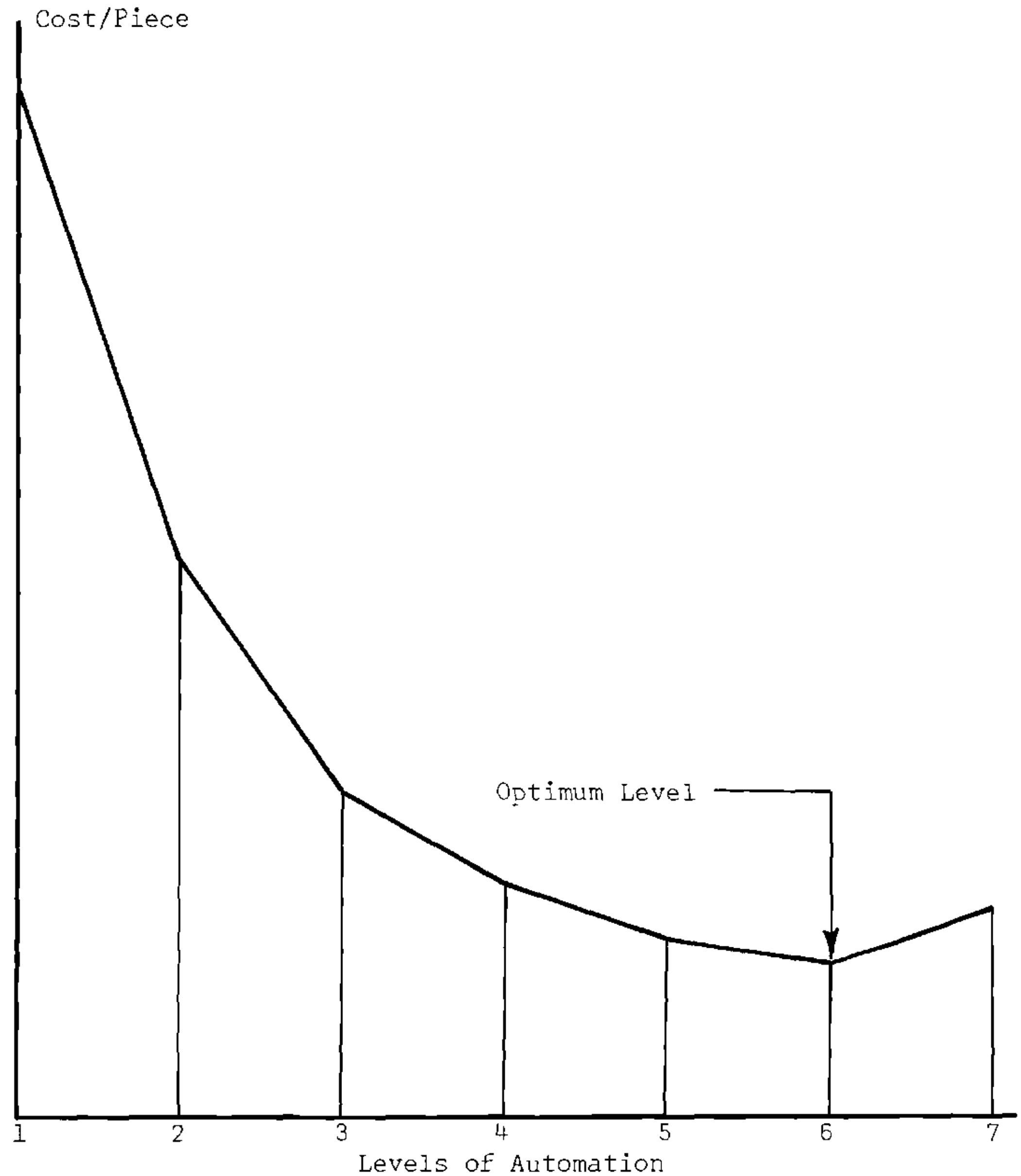

Figure 3. Determination of the Optimum Level of Automation

(From V. L. Lossiyevskii and L. G. Pliskin, *Automation of Continuous Production Processes.)*

Figures 2 and 3 can be combined to give Figure 4 which shows the optimum level of mechanization for each manufacturing operation. It should be emphasized that different operations usually have different optimum degrees of mechanization. For the example shown in Figure 4, the optimum levels for operations 1, 2, 3, 4, 5, and 6, are 6, 4, 6, 7, 7, and 4 successively.

The second part of this thesis deals with the selection of materials handling equipment. The equipment can be classified as:

1. *Mutually exclusive.* In this case, one handling activity is considered, and one particular type of materials handling equipment is to be chosen from several possibilities.

2. *Independent.* Several handling activities are considered, and only one piece of materials handling equipment is proposed for each handling activity. The objective then is to choose some or all of these equipment types, according to the rate of return, as long as funds are available.

3. *Mixed.* This is a combination of mutually exclusive and independent machines. In other words, there are many processes requiring investments, some or all of which have mutually exclusive equipment types.

The selection will be determined after economic and intangible factors analyses. The methods for choosing among project alternatives are:

1. Present worth method.
2. Final worth method.
3. Equivalent annual cost method.

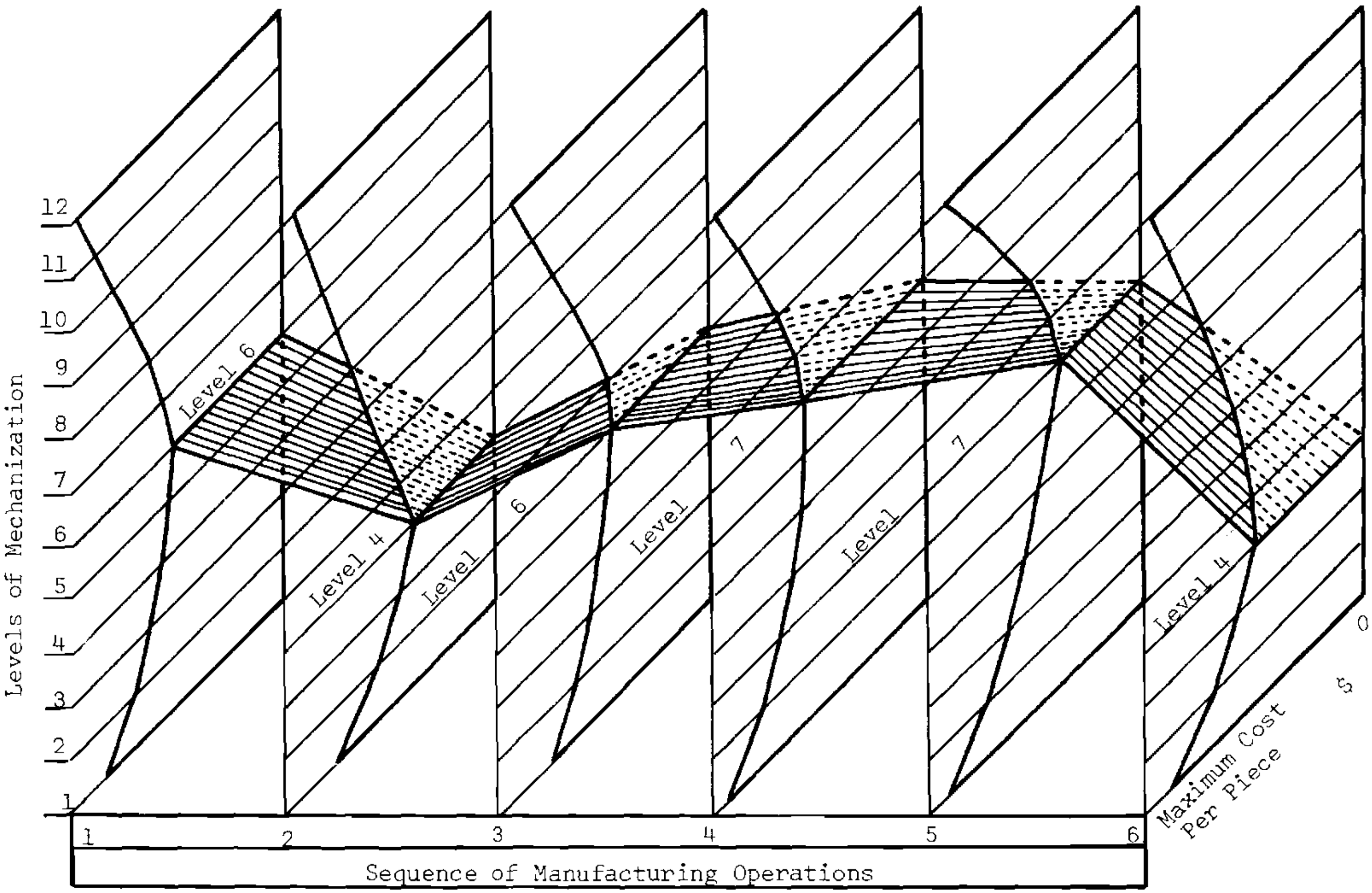

Figure 4. Determination of Optimum Levels of Mechanization for Different Manufacturing Operations

4. Rate of return method.

5. Rate of return on additional investment method.

6. Adjusted rate of return on additional investment method.

Although helpful in the case of mutually exclusive and/or independent equipment types, methods 1, 2, 3, and 4 are not very effective in the case of a mixture of types of equipment, especially when many sources of funds with varying rates of interest are available.

A brief review of the listed methods is presented here. For simplicity the annual operating costs are assumed to be constant. For variable annual operating costs, see (4).

1. *Present worth method.* The piece of equipment which has the minimum present worth is chosen. The present worth is given by the formula:

$$P = INV + AOC \frac{(1 + i)^n - 1}{i\ (1 + i)^n}$$

2. *Final worth method.* The final worth is given by the expression:

$$F = INV\ (1 + i)^n + AOC \frac{(1 + i)^n - 1}{i}$$

The equipment type that has the minimum final worth is chosen.

3. *Equivalent annual cost method.* This method can be directly applied, even in case of different service lives. The equivalent annual

cost is given by the formula:

$$EQAC = AOC + INV \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

The piece of equipment which has the minimum EQAC is chosen.

The present worth method, the final worth method, and the equivalent annual cost method, are mainly applied to the mutually exclusive type of projects. They can also be applied to the independent and/or the mixed type of projects, but combinations of projects rather than single projects should be considered.

4. *Rate of return method.* This method can be used for independent projects. Since there is no direct return from the materials handling equipment, but rather, annual payments are required, direct application of this method to materials handling equipment is not applicable.

5. *Rate of return on additional investment method.* This method (4) can be outlined in the following steps:

a. Equipment types are arranged starting with least capital investment and ending with maximum capital investment.

b. Service lives are reduced to the same standard service life. Accordingly, the annual operating cost should be adjusted.

$$INV \frac{i(1 + i)^n}{(1 + i)^n - 1} + AOC = INV \frac{i(1 + i)^{SS}}{(1 + i)^{SS} - 1} + AAOC$$

c. The capital recovery factor for each piece of equipment, starting from the second is calculated. The capital recovery factor for the Jth piece of equipment is given by the formula:

$$CRF\ (J) = AS\ (J)/ADINV\ (J)$$

where $AS\ (J) = AAOC\ (J - 1) - AAOC\ (J)$

$$ADINV\ (J) = INV\ (J) - INV\ (J - 1)$$

d. The rate of return on additional investment is calculated, starting from equipment number 2. This can be calculated from the formula:

$$CRF = \frac{RR\ (1 + RR)^{SS}}{(1 + RR)^{SS} - 1}$$

e. The equipment which has the largest investment, and meanwhile has a rate of return equal to or greater than the rate of interest is chosen. This method, unless adjusted, may lead to erroneous results.

6. *Adjusted rate of return on additional investments method.* This method has been developed by Dr. Shizuo Senju (7), and is the same as number 5, above, but with a slight change. After the rates of return are calculated for different equipment types, a diagram is

plotted between the additional investments and the rates of return. Through inspection, all unqualified pieces of equipment are eliminated. An unqualified equipment type is one which has a rate of return less than that of the next. An adjusted rate of return for any piece of equipment following an unqualified one should be calculated according to the formula:

$$NCRF = \frac{ARR\ (1 + ARR)^{SS}}{(1 + ARR)^{SS} - 1}$$

where: NCRF = NAS/NADINV. For the example shown in Figure 5, the piece of equipment number 4 is unqualified, and:

$$NAS\ (5) = AAOC\ (3) - AAOC\ (5)$$

$$NADINV\ (5) = INV\ (5) - INV\ (3)$$

After the adjusted rates of return have been calculated, the same criterion for the selection of the best piece of equipment in the rate of return on additional investment method is used.

This method is used in case of mutually exclusive equipment types. It can also be used in the mixed case, and is powerful especially in the case of large numbers of candidates, limited amount of funds, and different sources of funds with varying rates of interest.

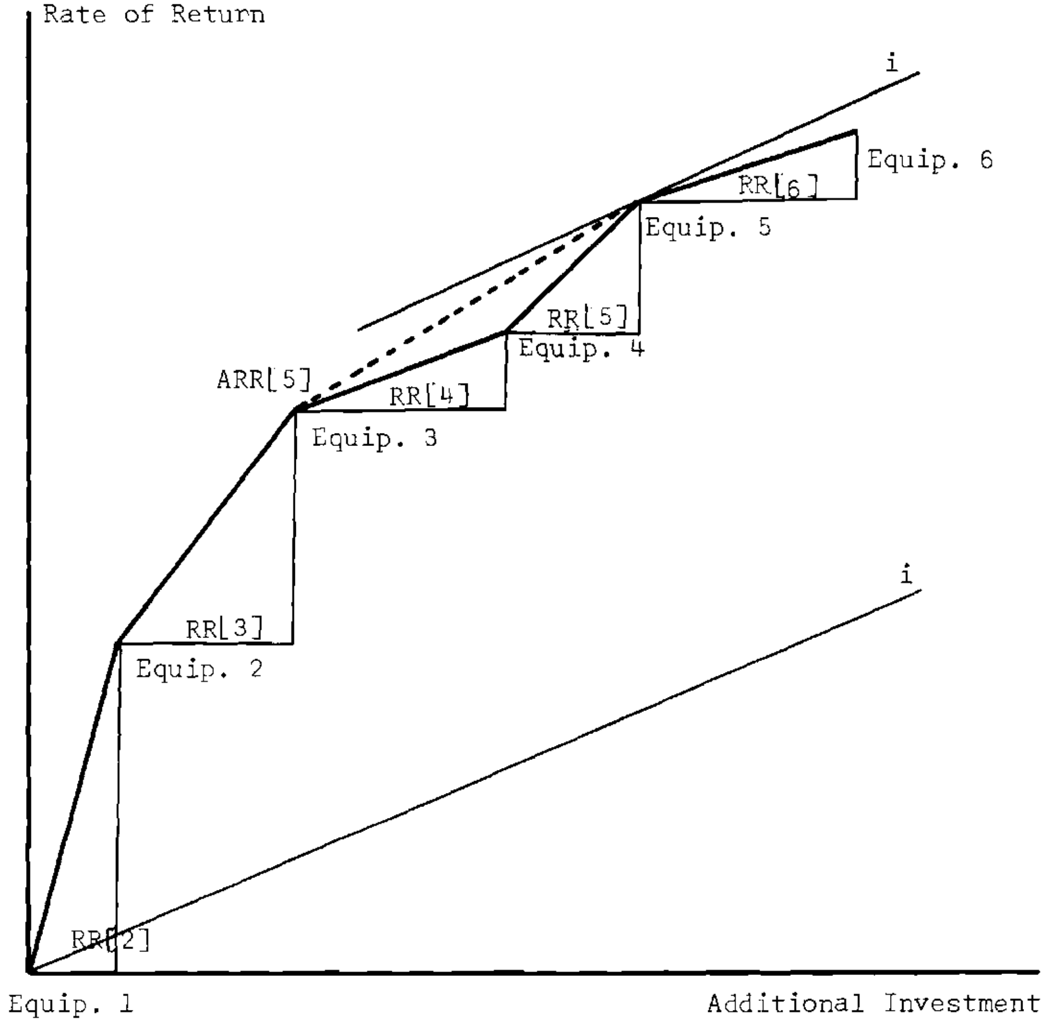

Figure 5. Adjusted Rate of Return on Additional Investment

CHAPTER III

LEVELS OF MECHANIZATION

The concept of mechanization can be applied to both handling and production activities. It is worth noting that one should not mechanize handling as a separate unit and mechanize production activities as another separate unit. Both handling and production activities should be mechanized together in such a way as to have continuous flow of production.

Bright has developed 17 levels of mechanization and Lossiyevskii and Pliskin have developed 20 levels of mechanization, as discussed in Chapter I. By the same logic, it is possible to develop a similar set of levels which are more suitable to handling activities. These levels are:

1. Hand
2. Hand Equipment
3. Mechanized Hand Equipment
4. Gravity Equipment
5. Power Equipment, Hand Control
6. Power Equipment, Remote Hand Control
7. Power Equipment, Program Control
8. Power Equipment, Feedback Control
9. Adaptive System Equipment
10. Fully Automated System Equipment

The following description will classify the distinction between the levels:

1. *Hand.* This level means pure manual handling. Naturally this method of handling is suitable primarily for a small quantity of production and provided that the parts being handled are light enough. In addition to the quantity and weight restrictions for manual handling, there are many others.

2. *Hand Equipment.* A typical example is a hand platform truck or a dolly. The operator is the source of power, but he does the handling with the aid of equipment. The use of this level of mechanization may also be limited by the amount of production.

3. *Mechanized Hand Equipment.* The main difference between this level and the preceding one is that the work is done with the aid of a simple mechanism, thus reducing the effort required for handling. An example is a manually operated hoist. The source of power is the operator himself, with his effort being supplemented by a mechanical device. No external power is required.

4. *Gravity Equipment.* In this level, gravity does the job of handling. No external power is required. In this particular level, some question might arise as to whether levels 3 and 4 should be reversed. This may seem logical, since the equipment types under level 3 are usually more complex than those under level 4 from the point of view of the design and mechanisms used. However, the more sophisticated equipment is not necessarily the more complex in design, but, rather, it is the one which reduces the manual effort and gives a better control of the objects being handled. That is why gravity equipment is given a

higher level of mechanization than mechanized hand equipment.

5. *Power Equipment, Hand Control.* Beginning at this level, external power facilitates the handling while the operator controls the equipment. A common example is a lift truck.

6. *Power Equipment, Remote Hand Control.* The distinction between levels 5 and 6 is that the control is not directly applied to the load. The overhead travelling crane is an example. The operator can control the vertical, lengthwise, and sidewise moves while sitting in the control cab. Another example is a system of conveyors under the control of a man in a separate room.

7. *Power Equipment, Program Control.* At this stage the control is no longer manual. As an example, on a programmed trolley conveyor, the trolleys follow a definite path and carries out a specific number of predetermined activities while they move, according to the program. No corrective action is involved in this level.

8. *Power Equipment, Feedback Control.* At this level, the actual function performed by the device is compared with the planned function and a corrective action takes place to assure carrying out the desired function. A feedback signal may cause a monorail conveyor unit to speed up or slow down, to the desired rate.

9. *Adaptive System Equipment.* Here the equipment control is self acting. The equipment moves between stations, and self determines to which station and at which rate parts will be handled. This is done according to signals given from the productive stations to the equipment.

10. *Fully Automated System Equipment.* The concept is not too different from that in level 9. The major difference is that in level 9, there is an adaptive system of equipment between a limited number of stations, and for one handling activity, while in level 10, there is a system of several pieces of adaptive equipment covering several production and handling activities, all being integrated.

A summary of the levels of mechanization of materials handling equipment is given in Figure 6. It should be noted that the degrees of mechanization of materials handling equipment should be completely integrated with the levels of mechanization of production equipment. If this is not taken into consideration, large queues of products could be waiting either to be handled or to be worked on.

The Concept of Degrees of Mechanization Applied to the Scope of Materials Handling Activities

It was pointed out, in Chapter II, that mechanization has two dimensions: level and span. The span can be looked at as the different materials handling activities. The following is a list of these activities suggested by Professors Apple and Bright.*

1. Packaging at vendor's plant.
2. Packing at vendor's plant.
3. Loading at vendor's plant.
4. Common carrier transportation to user plant.

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*James M. Apple, and James R. Bright, *Fundamentals of Materials Handling*, p. 2-2.

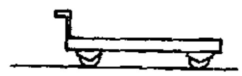
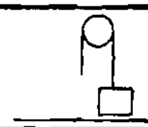
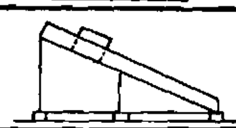
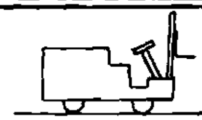
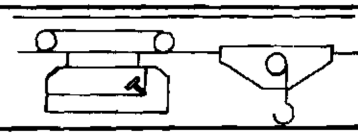
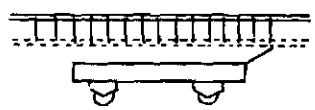
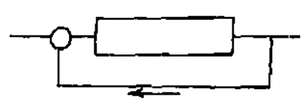
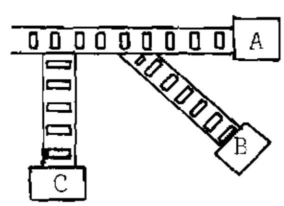
Classification		Level	Description	Examples	Characteristics
Manual Control	Manual Power	1	Hand		Man carries load.
		2	Hand Equipment		Equipment carries load.
		3	Mechanized Hand Equipment		Uses mechanical advantage.
	Gravity	4	Gravity Equipment		Positive control of object.
	External Power	5	Power Equipment, Hand Control		Power does work; man controls power.
		6	Power Equipment, Remote Hand Control		Control remote from load.
Automatic Control	External Power	7	Power Equipment, Program Control		Control according to program.
		8	Power Equipment, Feedback Control		Automatic correction, according to signal.
		9	Adaptive System Equipment		Integrated system of signals and actions.
		10	Fully Automated System Equipment		

Figure 6. A Summary of the Levels of Mechanization of Materials Handling Equipment

5. External plant transportation facilities.
6. Unloading.
7. Receiving operations.
8. Materials storage.
9. Materials issue and distribution.
10. Production activities.
11. Intra-departmental handling.
12. Workplace materials handling.
13. In-process storage.
14. Inter-departmental handling.
15. Service and auxiliary operations.
16. Quality control activities.
17. Packaging to customer specifications.
18. Packing to customer specifications.
19. Finished goods warehousing.
20. Stock picking.
21. Order assembly.
22. Loading operations.
23. Shipping operations.
24. Common carrier operations from plant.
25. Intra-plant handling.

Now the question arises, "To what extent can each one of these activities be mechanized?" The answer to this question depends upon many factors, such as:

1. Product involved.
2. The size, the shape, the dimensions, the materials, and the like.
3. The quantity being handled.
4. Facilities available.
5. Frequency of handling.
6. Speed of handling.
7. The degree of mechanization of production activities.

Despite the fact that all the above information is needed, one can, generally speaking, claim that even under the same conditions, different materials handling activities have a tendency to be mechanized to varying degrees. For example, mechanization of in-process handling, up to level 6, may be either easier or more difficult than the mechanization of inter-departmental handling to the same degree, under the same set of conditions.

For the sake of comparison, the degrees of mechanization for each handling activity may be classified as:

1. Easy.
2. Difficult.
3. Hard.

Although this might seem rather "loose," it will serve the present purpose. However, it is necessary to know something about the conditions under which the classification is made. The following assumptions are made:

1. The U. S. will be taken as a basis, for what might seem easy to mechanize in the U. S. may be difficult or even hard in a country with limited resources.

2. The degrees of mechanization will be different from one industry to another industry. Therefore, typical industries will be considered whereas specialized industries will be excluded.

3. Since the volume of production is one of the most decisive factors in determining the appropriate degree of mechanization, the size of the plant considered will be classified as:

(1) Small.

(2) Medium.

(3) Large.

It also seems necessary to include a second "dimension" in the problem of relating the appropriate level of mechanization to different handling activities. This second dimension concerns the feasibility of mechanization. EVen in the case of a large volume of production, manual handling may be "easy" from the points of view that:

1. No equipment is required.
2. No installation is required.
3. No training period to use the machinery is required.
4. No maintenance is required.

Although manual handling is easy, it is frequently unfeasible, for high production volume, due to:

1. Higher handling cost.
2. Closer supervision is required.
3. Limited capacity.

Hence, the need for a secondary classification is required. The degree or degrees of mechanization can be viewed as:

1. Feasible.

2. Unfeasible.

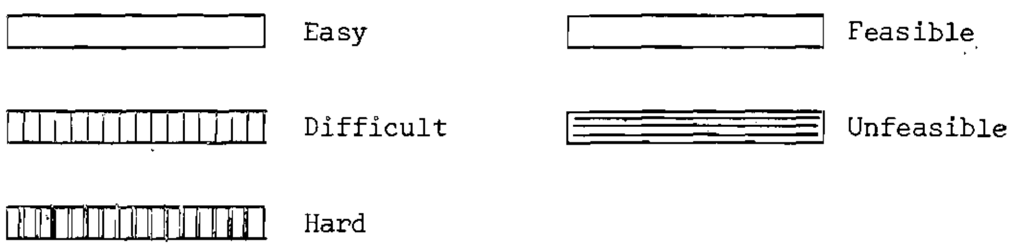
Figures 8, 9, and 10 attempt to combine the following concepts:

1. Levels of mechanization.

2. Scope of materials handling activities.

3. Relative degrees of feasibility and difficulty for a typical industry in U. S. for a small plant, a medium plant, and a large plant.

The following is the legend to Figures 7, 8, and 9.



For example, column number 1 in Figure 7 (Packaging at Vendor's Plant) reads as follows:

A. *Difficulty dimension.*

   1. Levels 1, 2, 3, 4, 5, and 6 are designated "easy."

   2. Levels 7 and 8 are designated "difficult."

   3. Levels 9 and 10 are designated "hard."

B. *Feasibility dimension.*

   1. Levels 1 and 2 are designated "unfeasible."

   2. Levels 3, 4, 5, and 6 are designated "feasible."

   3. Levels 7, 8, 9, and 10 are designated "unfeasible."

From the above, it is obvious that for "Packaging at a Small Vendor's Plant," levels 3, 4, 5, and 6 represent the levels of mechanization with the optimum combination of feasibility and relative ease of application.

A line across the chart represents different situations according to the activity considered. For example, in Figure 7, degree of mechanization number 7, represents a difficult to apply but feasible level of mechanization in the case of "Packaging at Vendor's Plant," while the same degree represents a hard to apply and unfeasible level of mechanization in the case of "External Plant Transportation Facilities." This again emphasizes that different materials handling activities do not have to be mechanized to the same degree.

Comparing the three charts in Figures 7, 8, and 9, it can be observed that the left-hand portion of the columns under each activity are similar. This means that the ease or difficulty of application does not depend upon the size of the plant. However, the feasibility of mechanization will vary according to the size of the plant.

The bounded "bands" shown across the center of Figures 7, 8, and 9 represent the range of recommended degrees of mechanization for each handling activity. They show the degrees of mechanization which are feasible and meanwhile are not hard to achieve.

Figure 10 shows the relative positions of the bands for a small plant, a medium plant, and a large plant. It can be observed that the bands are shifted upwards as the plant size increases. This again emphasizes the fact that it is more logical to automate in case of high level of production.

Although Figures 7, 8, 9, and 10 may need some further development, the general idea and concept can be understood.

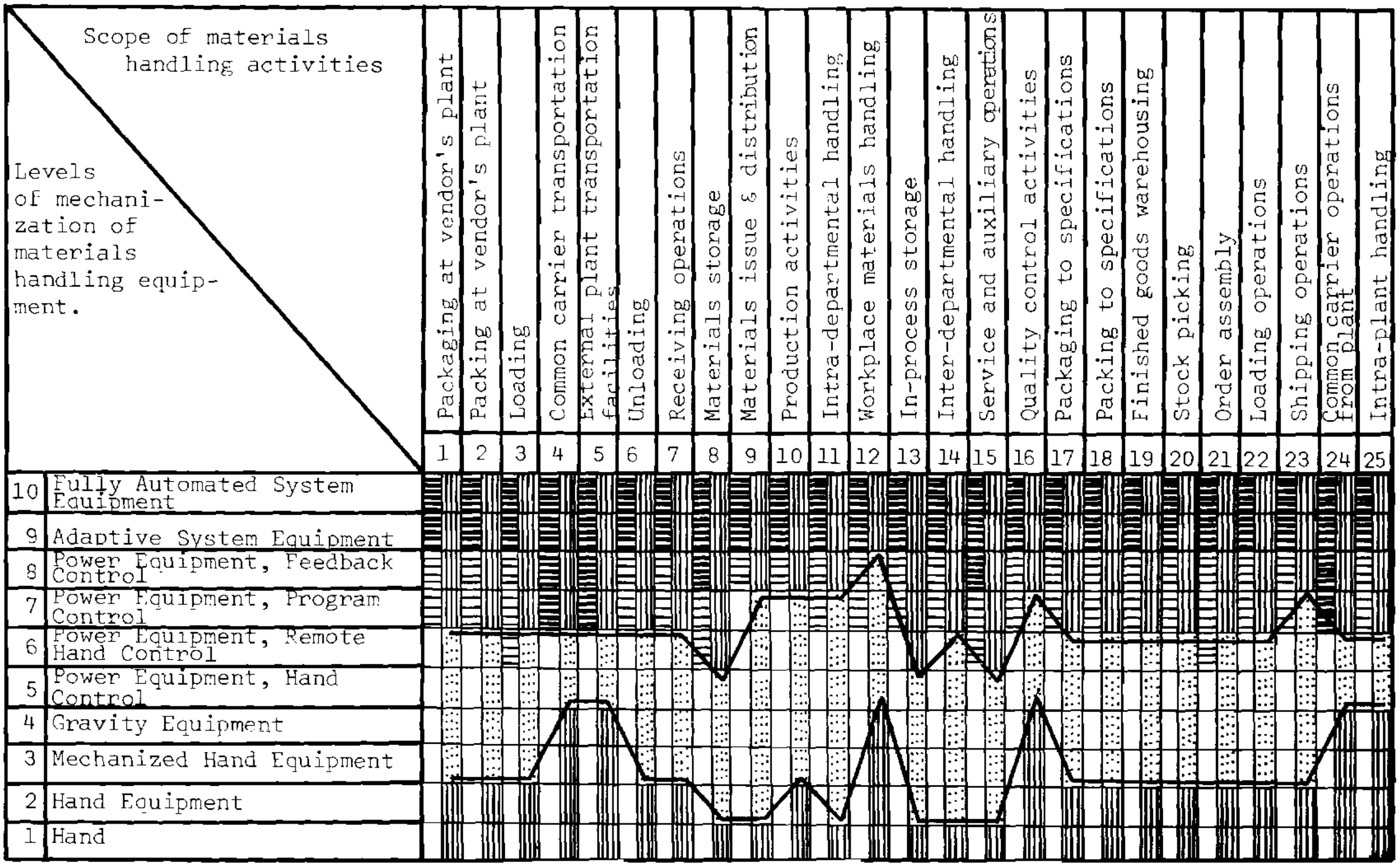


Figure 7. The Concepts of Levels of Mechanization and Scope of Materials Handling Activities--Typical Manufacturing Industry in U. S.--Small Plant

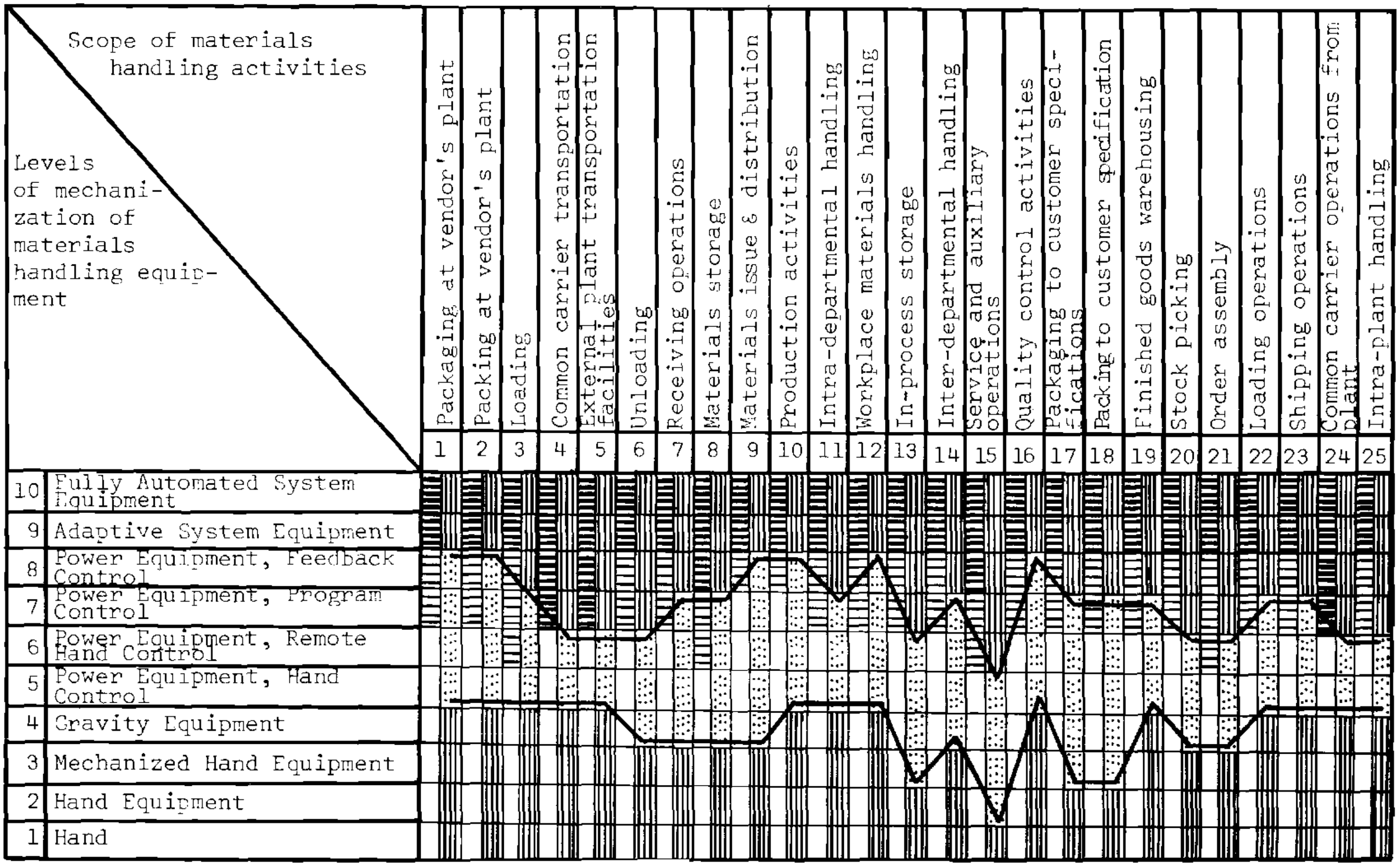


Figure 8. The Concepts of Levels of Mechanization and Scope of Materials Handling Activities--Typical Manufacturing Industry in U. S.--Medium Plant

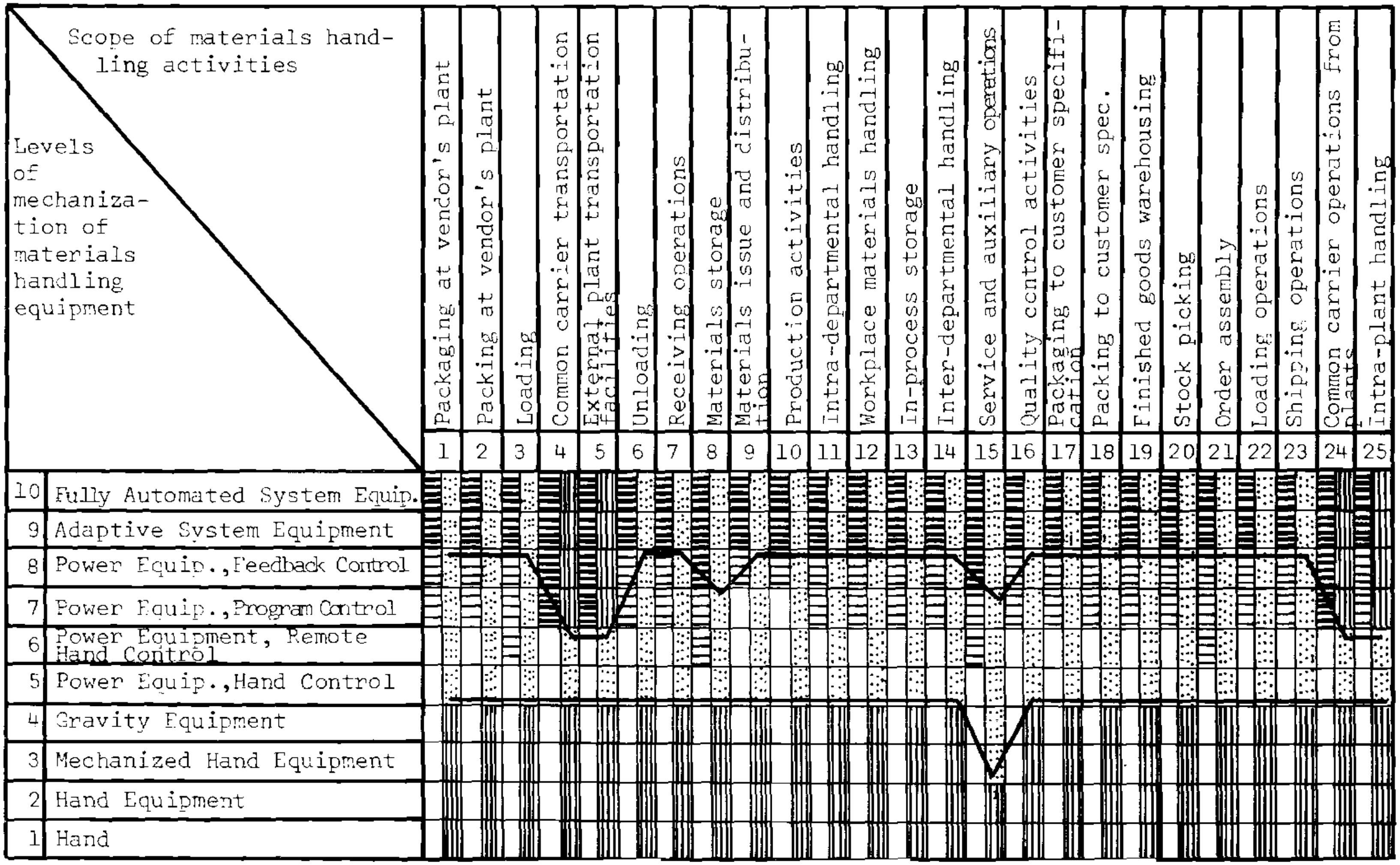


Figure 9. The Concepts of Levels of Mechanization and Scope of Materials Handling Activities--Typical Manufacturing Industry in U. S.--Large Plant

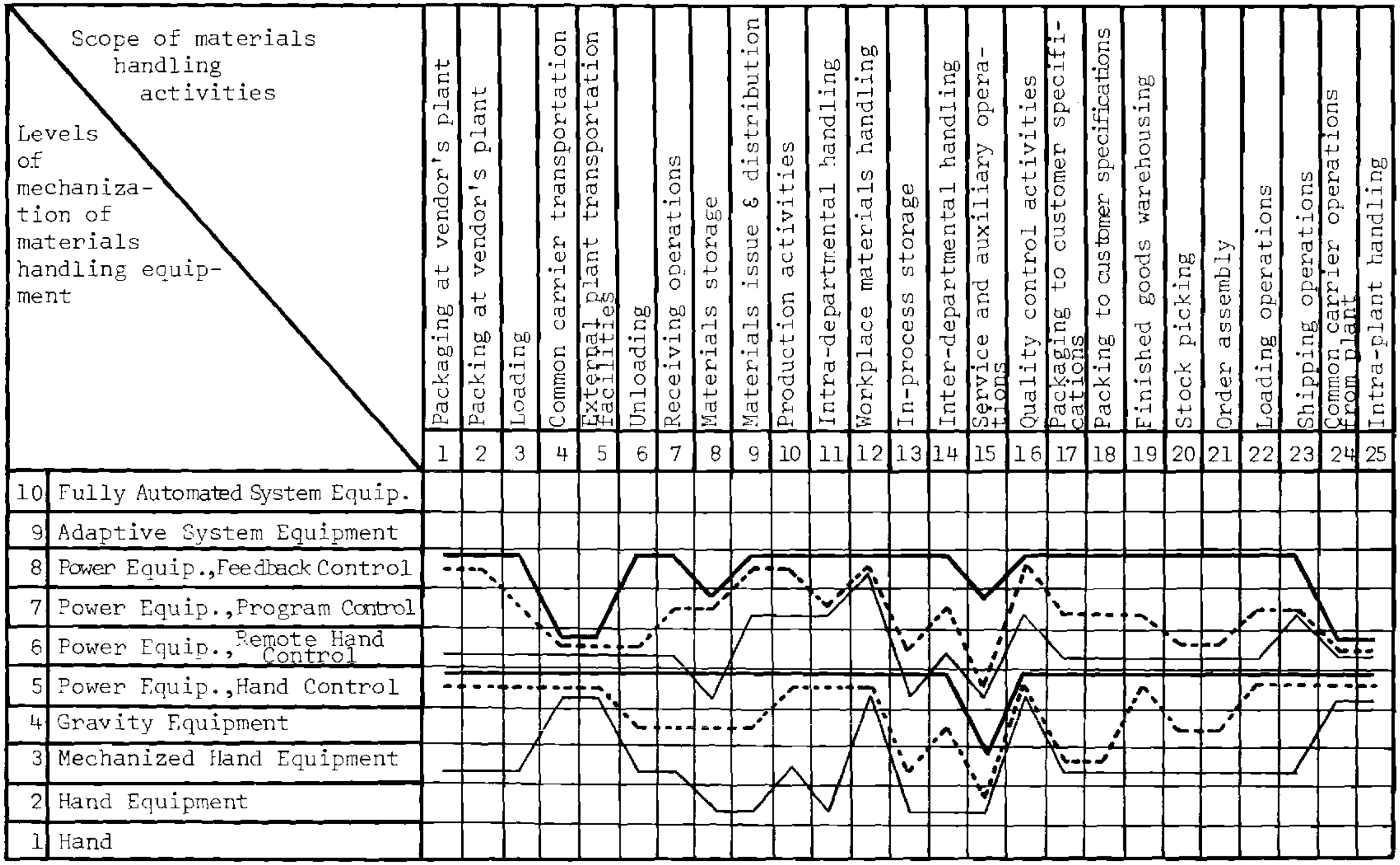


Figure 10. Relative Positions of the Bounds of Feasibility and Ease of Application in Case of a Small Plant ———, a Medium Plant - - - -, and a Large Plant ▬▬

CHAPTER IV

THE SELECTION OF MATERIALS HANDLING EQUIPMENT

It is not an easy task to select the appropriate equipment for a handling activity. The major part of the problem lies in the enormous number of possible materials handling equipment types available.

This thesis will develop an approach to guide the method of selection. The following steps, to be discussed later, are suggested:

I. Identify and determine the scope of the problem.

II. Define the problem.

III. Collect the data.

IV. Determine the level or levels of mechanization which best fit the given case.

V. With the aid of a chart, all pieces of equipment which have the chosen degree or degrees of mechanization are possible candidates for solutions.

VI. Eliminate the pieces of equipment which do not fit into the particular situation.

VII. Make an economic analysis to facilitate choosing among the remaining pieces of equipment.

VIII. Review and trade off intangible factors against economy.

IX. Choose the best equipment.

The general procedure is outlined in Figure 11. This method will not solve the problem. However, it will surely guide the materials handling engineer toward the selection of the proper degree of mechanization and the proper selection of the equipment type.

The method will now be explained in detail. Step I (identify the problem) and step II (define the problem) are extensively discussed in the literature (1), and hence need not be explained. Steps III through IX represent the major part of this study.

Step III: Collect the Data.

What is meant by the data here, are those factors which constitute the minimum information required to determine the suitable degree or degrees of mechanization. There are many factors which affect mechanization, which pertain either to the material being moved or to the type of movement. The factors are:

A. Factors classified under the term Material:

1. Quantity. The quantity or the volume of production per unit of time is considered the most decisive factor in selecting the appropriate degree of mechanization. It is obvious that a higher degree of mechanization will be justified when a large volume of production is to be handled. However, in some situations it is difficult to highly mechanize the handling operation, even in the event of large quantities.

Professor Bright* says:

> . . . there are certain physical facts, economic forces and engineering difficulties that make automatic production either impossible, technically impractical, or exhorbitantly expensive.

*James R. Bright, *Automation and Management,* pp. 30-31.

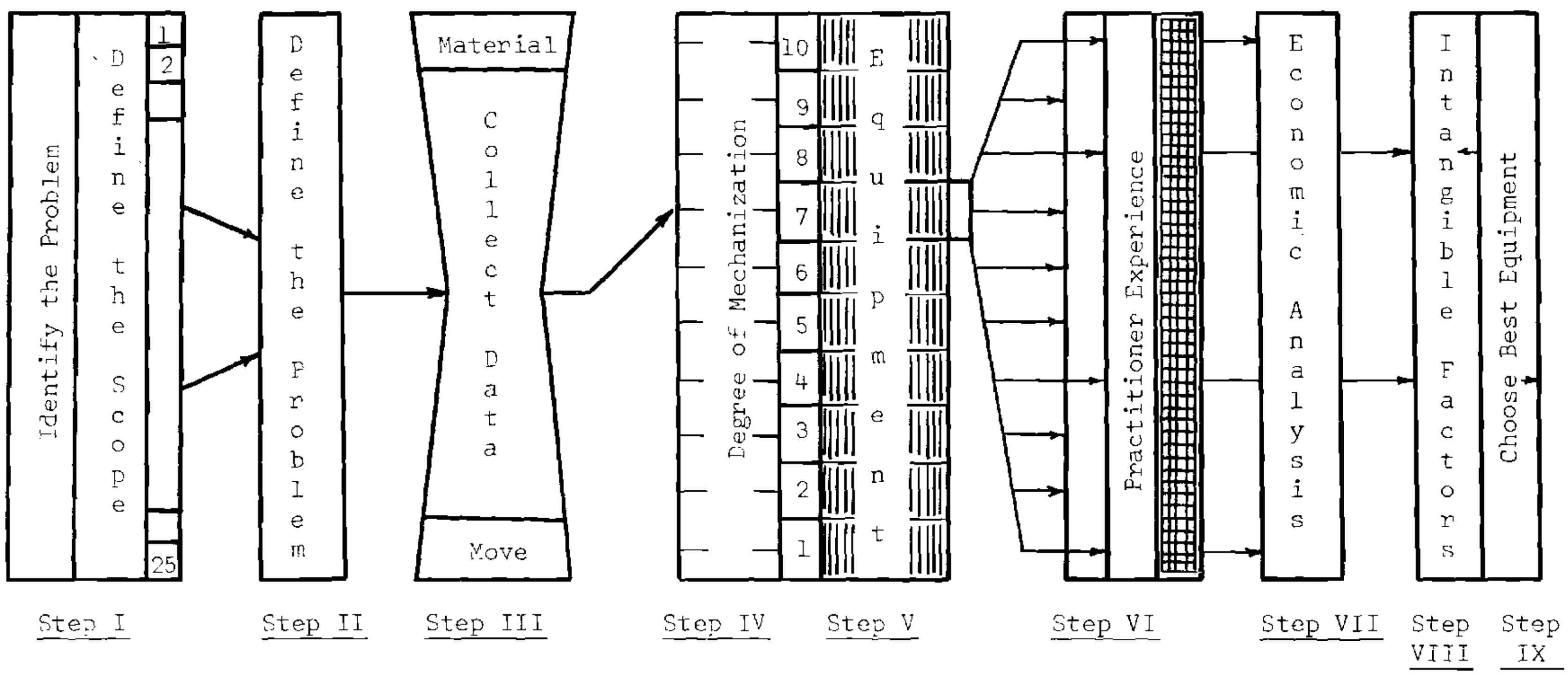


Figure 11. An Outline of the Approach Used in the Selection of Materials Handling Equipment

Confronted with this kind of problem, the automation enthusiast usually backs off by saying that, of course, one must have a reasonable volume to assure automation: "given enough volume, anything can be successfully automated." Volume by itself, however, does not necessarily make automation practical.

For the purpose of the approach presented in this thesis, the volume of production will be viewed as:

1. Small.

2. Medium.

3. Large.

4. Very large.

These terms are not distinctly separated, which might lead to some confusion, since what one person may consider a medium volume of production may be considered as a large volume of production by someone else. However, quantitatively distinctive separating limits are very difficult to establish, due to the fact that they should necessarily change from one situation to another, from one industry to another, and even from one country to another.

Since the volume of production is one factor in deciding the level or degree of mechanization, an attempt will be made to suggest a number of mechanization levels for each factor.

For small quantities of productions any level between 1 and 5 may be chosen. This means that if we have a handling activity, with a small volume of production being moved, then from the point of view of quantity only, level 1, 2, 3, 4, or 5 may be suitable depending on other factors.

Similarly, levels 2, 3, 4, 5, 6, and 7 are recommended for a medium production quantity. For a large quantity to be handled, any level from 4 up to 7 may be used, depending on other factors. Levels 6, 7, 8, 9, and 10 may be used in case of very high levels of production. See Figure 12.

2. Unit Volume. The unit volume is the volume of the unit being handled, whether this unit is a single item, a package, or a bulky material. Usually the unit volume would be expressed in cubic inches or cubic feet.

The unit volume as a factor in choosing a suitable degree of mechanization is not as important as the volume of production. The unit volume is classified as:

1. Small.
2. Medium.
3. Large.
4. Very large.

It is obvious that large volume items cannot be transported manually. Also very large volume products are difficult to handle automatically.

For each subfactor (small, medium, large, and very large), a set of levels or degrees of mechanization are suggested. See Figure 12.

3. Unit Weight. The concept of unit weight is slightly different from that of the unit volume, in the sense that the density is also considered. The units being moved can be considered:

1. Light.
2. Medium.
3. Heavy.

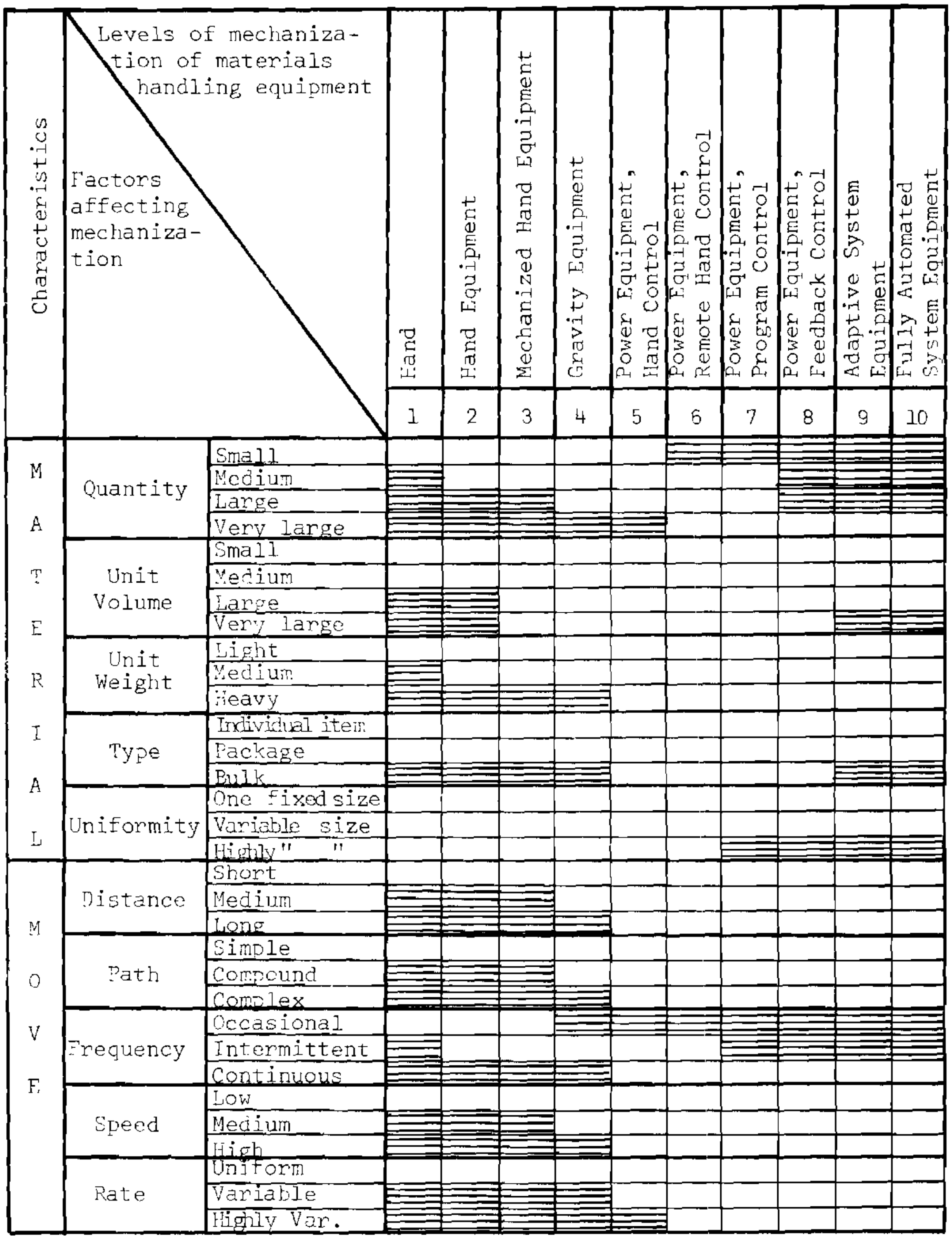


Figure 12. Relationships between the Factors and the Degrees of Mechanization

It is emphasized again that there is no clear-cut distinction between these subfactors. The interpretation of those terms will be left to the experience of the practitioner, within each industry. Figure 12 gives the levels suggested for each subfactor.

4. Type. The type here means more or less what material is being handled. From the type viewpoint, the material being moved can be classified as:

1. Individual item.
2. Package.
3. Bulk material.

Figure 12 may be consulted for the relationship between this factor and the levels of mechanization.

5. Uniformity. By the uniformity is meant the uniformity of the sizes of the units being handled. Products will be classified as having:

1. One fixed size.
2. Variables sizes.
3. Highly variable sizes.

Figure 12 may be consulted for the relationships between the uniformity and the degree of mechanization.

B. Factors classified under the term Move:

1. Distance. The distance which the item is transported can be classified as:

1. Short.
2. Medium.
3. Long.

For a short distance any degree of mechanization from 1 to 10 may be used, depending on other factors. For a medium distance, level number 4, 5, 6, 7, 8, 9, or 10 may be used. For a long distance any level from 5 to 10 may be used. See Figure 12.

It should be noted that the concept of the distance does not imply the complexity of the movement, it just indicates the distance travelled.

2. Path. The path represents the complexity of the movement. It can be classified as:

1. Simple.
2. Compound.
3. Complex.

The relationship between the degrees of mechanization and path is given in Figure 12.

3. Frequency. The frequency of the movement can be classified as:

1. Occasional.
2. Intermittent.
3. Continuous.

Figure 12 may be consulted for the relationship between frequency and degrees of mechanization.

4. Speed. The term speed means the average speed. It is classified as:

1. Low.
2. Medium.
3. High.

For the relationship between speed and levels of mechanization, see Figure 12.

5. Rate. The concept of the rate is different from that of the speed. By the rate is meant whether the speed is constant or variable. The rate can be classified as:

1. Uniform.
2. Variable.
3. Highly variable.

See Figure 12.

The chart given in Figure 12 attempts to show the relationship between the factors of importance in the analysis of the handling problem and the ten levels of mechanization.

It can be seen from the chart that 12 of the subfactors are of little or no significance in determining the level to be applied. This suggests that the decision must be made on the basis of those which are significant. In some cases, it may be necessary to review the subfactors which appear to be irrelevant.

Step IV: Select the Degree of Mechanization.

After the data have been collected, a group of suggested levels of mechanization related to each factor is available. Now it is necessary to combine these levels, to achieve a single or a narrow range of degrees of mechanization.

The method developed here is best explained by an example, for which the data are as follows:

1. Quantity: Large.
2. Unit volume: Medium.
3. Unit weight: Medium.
4. Type: Bulky.
5. Uniformity: Variable sizes.
6. Distance: Medium.
7. Path: Simple.
8. Frequency: Intermittent.
9. Speed: Low.
10. Rate: Uniform.

For each one of the factors, a number of levels of mechanization is applicable. Hence for each factor, all the possible degrees are checked (x). See Figure 13.

For example, since the quantity is large, check marks (x) are put under levels 4, 5, 6, and 7. After all factors are considered, the number of check marks (x) is counted for each degree of mechanization. For the given example, the results are summarized in Table 2.

Table 2. A Summary of the Degrees of Mechanization

Degree of Mechanization	1	2	3	4	5	6	7	8	9	10
Number of Check Marks (x)	5	7	7	9	10	10	9	8	7	7

This indicates that levels 5 and 6 should be considered. It is obvious in this example, that levels 1, 2, and 3 represent under-

Characteristics	Factors affecting mechanization		Hand (1)	Hand Equipment (2)	Mechanized Hand Equipment (3)	Gravity Equipment (4)	Power Equipment, Hand Control (5)	Power Equipment, Remote Hand Control (6)	Power Equipment, Program Control (7)	Power Equipment, Feedback Control (8)	Adaptive System Equipment (9)	Fully Automated System Equipment (10)
MATERIAL	Quantity	Small										
		Medium										
		Large				x	x	x	x			
		Very large										
	Unit Volume	Small										
		Medium	x	x	x	x	x	x	x	x	x	x
		Large										
		Very large										
	Unit Weight	Light										
		Medium		x	x	x	x	x	x	x	x	x
		Heavy										
	Type	Individual item										
		Package										
		Bulk					x	x	x	x		
	Uniformity	One fixed size										
		Variable sizes	x	x	x	x	x	x	x	x	x	x
		Highly " "										
MOVE	Distance	Short										
		Medium				x	x	x	x	x	x	x
		Long										
	Path	Simple	x	x	x	x	x	x	x	x	x	x
		Compound										
		Complex										
	Frequency	Occasional										
		Intermittent		x	x	x	x	x				
		Continuous										
	Speed	Low	x	x	x	x	x	x	x	x	x	x
		Medium										
		High										
	Rate	Uniform	x	x	x	x	x	x	x	x	x	x
		Variable										
		Highly Var.										

Figure 13. An Example of the Relationships Between the Factors and the Degrees of Mechanization

mechanized solutions, while levels 9 and 10 represent overmechanized solutions. Levels 4, 7, and 8 are possibilities.

This method may not give the optimum level of mechanization for the following reasons:

1. No clear-cut distinctions between the subfactors are established.
2. The degrees of mechanization applicable for each factor are established on a subjective basis.

However, this method for determining the level of mechanization will serve as a guide in the selection of the proper materials handling equipment.

Step V: Select All Possible Pieces of Equipment.

Different types of equipment are mechanized to different degrees. For example, a chute may have a level of mechanization of 4, whereas a screw conveyor may have a level of mechanization of 5.

Figures 14, 15, and 16 show an attempt to assign a set of degrees of mechanization to some of the more commonly used types of materials handling equipment. It is clear that a single type of equipment can be mechanized to different degrees. For example, a power and free conveyor can be mechanized from the fifth degree of mechanization to the eighth level.

It is to be remembered from Step IV that a level of mechanization has been recommended. Now by using this level, one can obtain a number of equipment types to be considered. Of course, some of these equipment types may not be applicable to the particular situation. These

Equipment		Levels of Mechanization									
		1	2	3	4	5	6	7	8	9	10
1	Apron Conveyor					═══					
2	Arm Conveyor					═══	═══				
3	Belt Conveyor					═══	═══	═══	═══		
4	Bucket Elevator					═══	═══				
5	Chute				═══						
6	Drag Chain Conveyor					═══	═══	═══			
7	Flight Conveyor					═══	═══				
8	Pneumatic Conveyor					═══					
9	Power and Free Conveyor					═══	═══	═══	═══		
10	Roller Conveyor		═══	═══	═══	═══	═══	═══	═══		
11	Rolling Chain Conveyor				═══	═══	═══	═══			
12	Screw Conveyor					═══					
13	Slat Conveyor					═══	═══				
14	Sliding Chain Conveyor					═══	═══	═══			
15	Suspended Tray Conveyor					═══	═══				
16	Tow Conveyor			═══	═══	═══	═══	═══	═══	═══	═══
17	Trolley Conveyor			═══	═══	═══	═══	═══	═══	═══	═══
18	Cross Bar Conveyor					═══	═══	═══			
19	Oscillating Conveyor					═══	═══				

Figure 14. Levels of Mechanization Corresponding to Different Types of Conveyors

Equipment		Levels of Mechanization									
		1	2	3	4	5	6	7	8	9	10
1.	Hoist										
2.	Gantry Crane										
3.	Overhead Traveling Crane										
4.	Monorail Conveyor										
5.	Trolley Conveyor										

Figure 15. Levels of Mechanization Corresponding to Different Types of Overhead Equipment

Equipment		Levels of Mechanization									
		1	2	3	4	5	6	7	8	9	10
1.	Platform Truck										
2.	Hand Lift Truck										
3.	Fork Truck										
4.	Remote Controlled Tractor Trailer										
5.	Tractor										

Figure 16. Levels of Mechanization Corresponding to Different Types of Industrial Vehicles

will be eliminated afterwards in Step VI.

At this stage, the practitioner will obtain a number of equipment types which may be used for the handling activity under consideration. As an example, if the recommended degree of mechanization is 4, then, with the aid of Figures 14, 15, and 16, the possible equipment types to be considered are: Chute, Roller Conveyor, Rolling Chain Conveyor, Tow Conveyor, Trolley Conveyor, and Monorail.

Step VI: Eliminate Equipment Types Not Applicable.

This step is necessary before going further into a detailed economic analysis and consideration of intangible factors. Now the materials handling engineer has a set of possible equipment types. It is obvious that some of these can be eliminated from the first trial, simply because they do not fit into the specific situation with which the practitioner is confronted. This method of elimination is completely left to the experience of the materials handling engineer and to his evaluation of the situation. This will narrow down the possibilities to be considered further.

Step VII: Economic Analysis.

This step involves an economic analysis of equipment types. Estimation of the capital investment and of the operating costs are required. Some of the cost items under capital investment and operating costs are listed below:

A. Capital investment

1. Invoice price of the equipment.
2. Installation charges.

3. Maintenance facilities.

4. Fueling and/or power facilities.

5. Freight and other transportation.

6. Design work.

7. Supplies.

8. Other charges.

B. Operating costs

1. Operating personnel.

2. Power and/or fuel costs.

3. Lubricant.

4. Maintenance labor.

5. Maintenance parts and materials.

6. Taxes.

7. Insurance.

8. Supervision.

9. Clerical.

10. Other.

As discussed in Chapter II, there are many methods of choosing between equipment types. For the purpose of this thesis, the adjusted rate of return on additional investment method (7), and/or the equivalent annual cost method (4), (6) will be used.

The application of these two methods to the materials handling equipment can best be explained by a numerical example. In this example a variety of activities is considered.

Numerical Example

Three handling activities A, B, and C are considered. Equipment types A_1, A_2, A_3, A_4, and A_5 are selected for activity A; B_1, B_2, B_3, and B_4 are selected for activity B; and C_1, C_2, C_3, C_4, and C_5 are selected for activity C.

Table 3 gives the capital investments, and the annual operating costs of the different equipment types. The equipment types are assumed to have ten years service life, and further, they are assumed to have no salvage value at the end of their service lives.

Table 3. Data on Selected Equipment Types

A	INV $	AOC $	B	INV $	AOC $	C	INV $	AOC $
A_1	3,000	1,626	B_1	4,500	1,700	C_1	1,800	823
A_2	6,000	1,170	B_2	7,200	1,300	C_2	2,500	690
A_3	8,500	894	B_3	8,900	1,020	C_3	3,800	546
A_4	9,700	720	B_4	10,500	850	C_4	5,200	360
A_5	10,800	600				C_5	7,000	160

It is desired to determine the best combination of equipment types for the following two cases:

Case 1

Handling activities A, B, and C are completely independent, and there are no interrelationships between the equipment types. Further, all the possible 100 equipment combinations (5 x 4 x 5) are assumed to be feasible.

Case II

Only a portion of the 100 equipment combinations is feasible from the point of view of practical application, engineering, and technology.

Solution--Case I

The following three different sources of funds are considered:

1. Funds available are $25,000.

2. Interest rate is 6 per cent.

3. Money can be borrowed up to $10,000 at 6 per cent, and up to $50,000 at 9 per cent from another source.

The first step is to eliminate all unqualified equipment types and to calculate the adjusted rates of return. Following the outline given in Chapter II, the results in Tables 4, 5, and 6 are obtained.

After the adjusted rates of return have been calculated, they are arranged in a decreasing order and plotted against the additional investments required for each. Of course, the additional investment that has a higher rate of return is given priority.

By inspecting Figure 17, the following results are obtained:

1. In case of $25,000 available, the following investments and/or additional investments are considered:

A_1, B_1, C_1, $(C_2 - C_1)$, $(B_3 - B_1)$, $(A_2 - A_1)$, $(C_4 - C_2)$, and $(A_4 - A_2)$.

In other words, the following equipment types are recommended:

$$A_1 + (A_2 - A_1) + (A_4 - A_2) = A_4$$

$$B_1 + (B_3 - B_1) = B_3$$

$$C_1 + (C_2 - C_1) + (C_4 - C_2) = C_4$$

Table 4. Adjusted Rates of Return for Activity A

EQUIP.	INV $	AOC $	AS $	ADINV $	CRF	QUALIFIED	NAS $	NADINV $	NCRF	ARR
A_1	3,000	1,626				Yes				
A_2	6,000	1,170	456	3,000	0.152	Yes	456	3,000	0.152	8.5%
A_3	8,500	894	276	2,500	0.110	No	x	x	x	x
A_4	9,700	720	174	1,200	0.145	Yes	450	3,700	0.121	3.6%
A_5	10,800	600	120	1,100	0.109	Yes	120	1,100	0.109	1.8%

Table 5. Adjusted Rates of Return of Activity B

B_1	4,500	1,700				Yes				
B_2	7,200	1,300	400	2,700	0.148	No	x	x	x	x
B_3	8,900	1,020	280	1,700	0.164	Yes	680	4,400	0.155	9 %
B_4	10,500	850	170	1,600	0.106	Yes	170	1,600	0.106	1.2%

Table 6. Adjusted Rates of Return of Activity C

EQUIP.	INV $	AOC $	AS $	ADINV $	CRF	QUALIFIED	NAS $	NADINV $	NCRF	ARR
C_1	1,800	823				Yes				
C_2	2,500	690	133	700	0.193	Yes	133	700	0.190	14.2%
C_3	3,800	546	144	1,300	0.111	No	x	x	x	x
C_4	5,200	360	186	1,400	0.133	Yes	330	2,700	0.122	3.8%
C_5	7,000	160	200	1,800	0.117	Yes	200	1,800	0.117	3 %

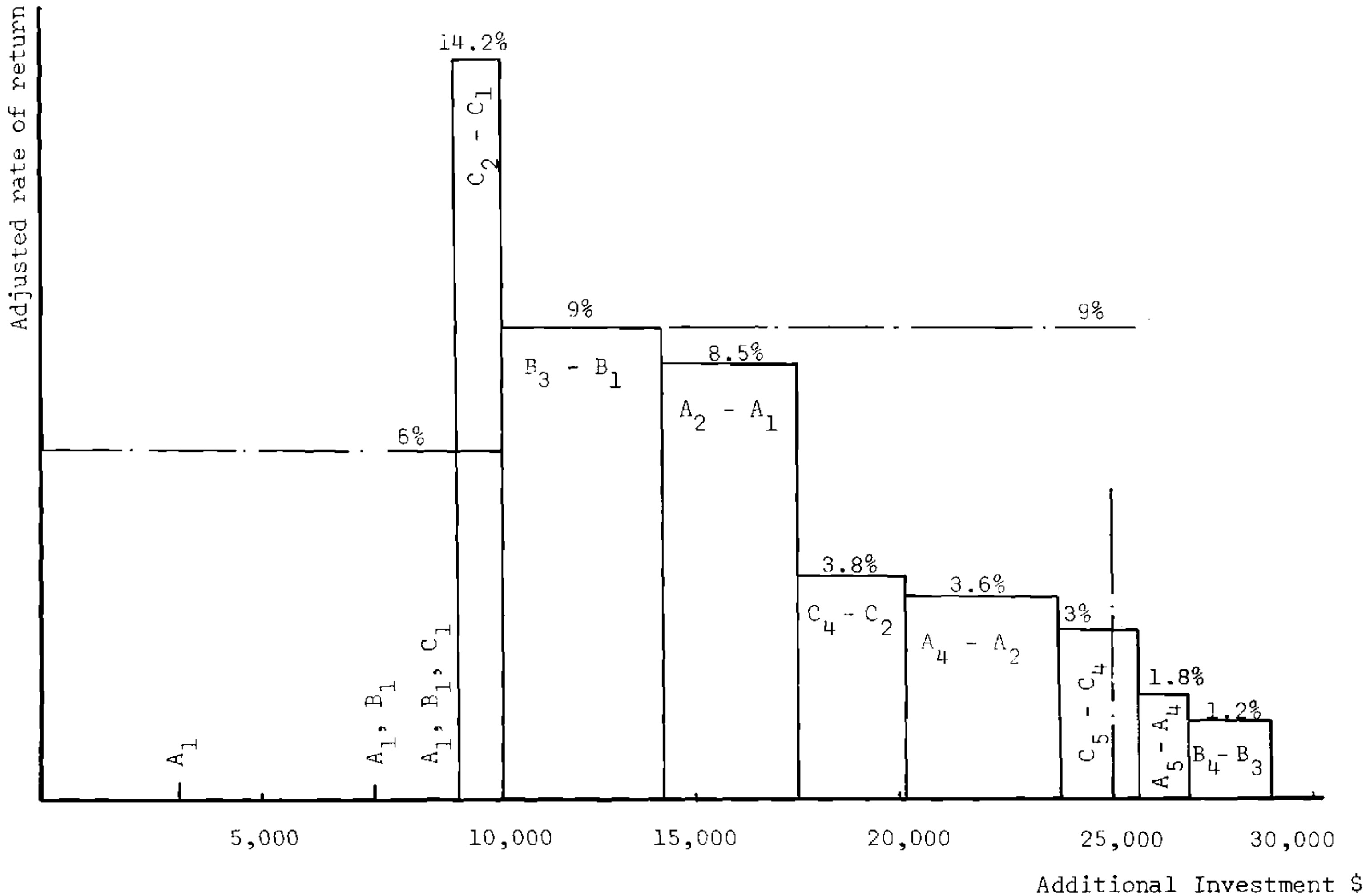


Figure 17. Adjusted Rates of Return vs. Additional Investments

2. In case of 6 per cent interest rate, equipment types recommended are A_2, B_3, and C_2.

3. In case of \$10,000 at 6 per cent, and \$50,000 at 9 per cent, equipment types recommended are A_1, B_3, and C_2.

Solution--Case II

Figure 18 shows the feasible combinations to be:

$A_1\ B_1\ C_1$, $A_1\ B_1\ C_4$, $A_2\ B_3\ C_1$, $A_2\ B_4\ C_3$, $A_3\ B_1\ C_3$, $A_3\ B_3\ C_2$, $A_4\ B_2\ C_5$, $A_4\ B_4\ C_4$, $A_5\ B_2\ C_2$, and $A_5\ B_2\ C_3$.

Following the outline given in Chapter II, on the basis of 6 per cent interest rate, the results in Tables 7 and 8 are obtained.

By inspecting Table 8, the equipment combination which has the minimum equivalent annual cost is $A_2\ B_3\ C_1$.

Table 7. Equivalent Annual Costs Corresponding to Handling Activities A, B, and C

A	EQAC \$	B	EQAC \$	C	EQAC \$
A_1	2,034	B_1	2,312	C_1	1,068
A_2	1,986	B_2	2,779	C_2	1,030
A_3	2,050	B_3	2,230	C_3	1,063
A_4	2,048	B_4	2,278	C_4	1,067
A_5	2,069			C_5	1,112

Table 8. Equivalent Annual Costs of the Feasible Equipment Combinations

Feasible Combination	Total INV $	Total EQAC $
A_1 B_1 C_1	9,300	5,414
A_1 B_1 C_4	12,700	5,413
A_2 B_3 C_1	16,700	5,284
A_2 B_4 C_3	20,300	5,327
A_3 B_1 C_3	16,800	5,425
A_3 B_3 C_2	19,900	5,310
A_4 B_2 C_5	23,900	5,439
A_4 B_4 C_4	25,400	5,393
A_5 B_2 C_2	20,500	5,378
A_5 B_2 C_3	21,800	5,411

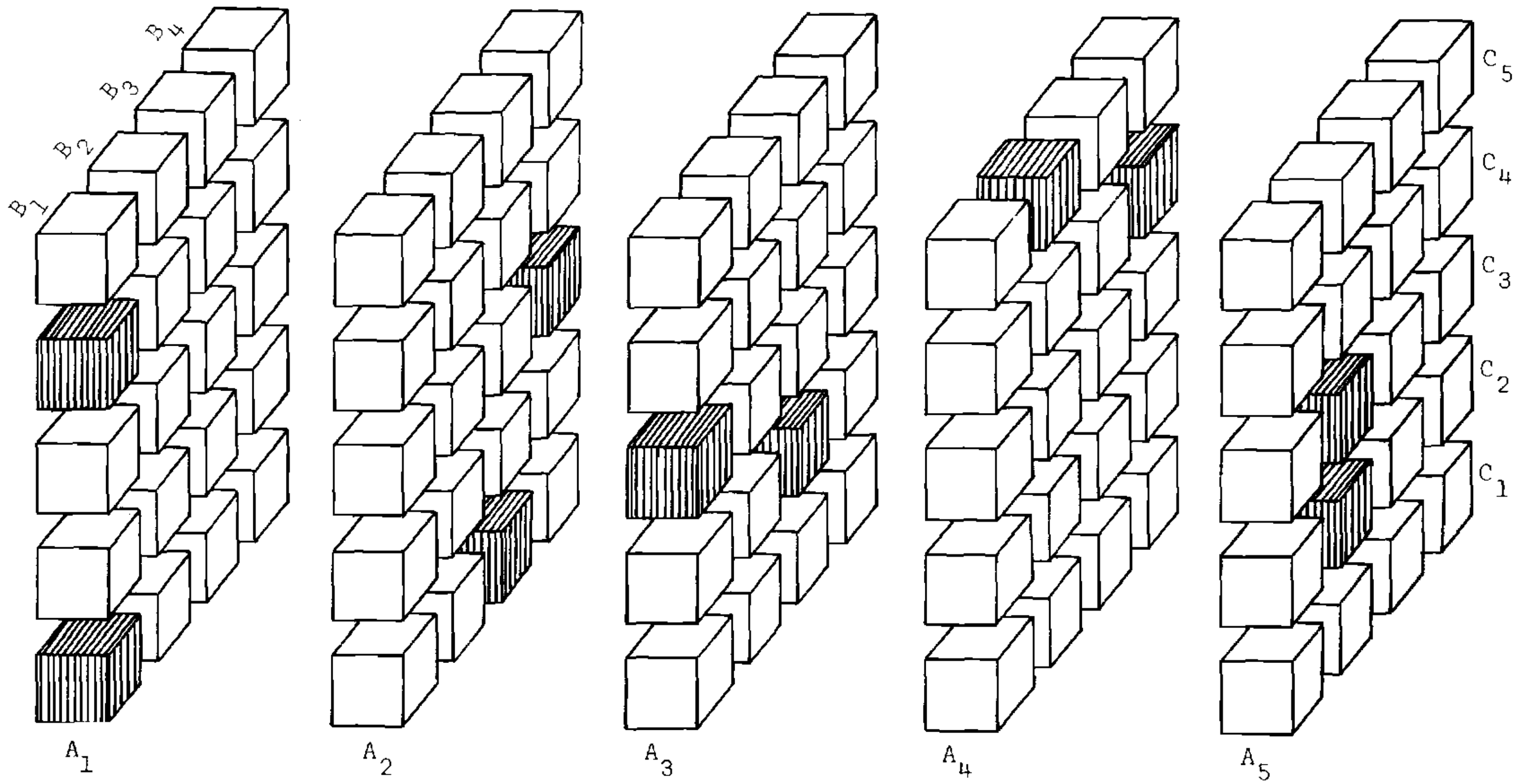


Figure 18. Feasibility of Equipment Combinations of Handling Activities A, B, and C

Step VIII: Intangible Factors Consideration.

These factors are more difficult to quantify and measure objectively. The method of attacking these factors will follow the outline given by Professors Apple and Bright (2). The most important intangible factors to be considered are:

1. Quality of the equipment.

2. Durability of the equipment.

3. Compatibility of the equipment with present handling system.

4. Standardization of equipment and/or components.

5. Flexibility of equipment in terms of capacity, as volume change.

6. Adaptability of equipment to possible future applications.

7. Complexity of equipment, both as to operation and maintenance.

8. Safety hazards and/or safeguards.

9. Rate of obsolescence.

10. Manufacturer's reputation.

11. Availability of equipment, or loss per month due to lack of availability.

12. Post sale advice and/or service.

13. Availability of service.

14. Availability of repair parts.

15. Trends in equipment cost.

16. Financial policies.

17. Effect of future changes on utilization of equipment.

18. Plans for expansion of plant and/or activity.

19. Labor relations aspects of displaced personnel.

20. Effect on morale.

Evaluation of intangible factors

Although difficult to evaluate, the intangible factors should be evaluated before a final decision is made on the total cost of the project under consideration. The method given by Professors Apple and Bright (2) is outlined in the following steps:

1. Eliminate the factors which do not apply to any of the alternatives under consideration.

2. Determine the relative importance of each factor. Assign an importance value for each factor, using 100 for the most important.

3. Adjust the values so that 100 is the total.

4. Evaluate each factor for each alternative, in terms of its relative importance to the project.

5. Determine the weighted evaluation rating.

6. Total weighted evaluation for each method.

A numerical example is shown in Table 9.

Now the practitioner is confronted with the complicated problem of how to translate the figure obtained from the intangible factors consideration into dollars. This will have to be left to the materials handling engineer experience. However, this does not reduce the importance of the intangible factors analysis which at least gives the relative ranking of the different pieces of equipment from the point of view of the intangible factors.

Table 9. Intangible Factors Evaluation

Factors in Order of Importance	Importance Value	Adjusted Importance Value	Alternatives Under Consideration			
			A		B	
			Rating	Weighted Rating	Rating	Weight Rating
Quality	100	25	90	22	72	18
Availability	80	21	80	17	72	15
Service	70	18	95	17	67	12
Obsolescence	50	13	100	13	85	11
Future Use	40	10	100	10	70	7
Complexity	30	8	80	6	100	8
Effect on Morale	20	5	100	5	60	3
TOTAL	390	100		90		74

Adapted from: James M. Apple, and James R. Bright, *Fundamentals of Materials Handling*, p. 11-10.

Step IX: Choose Best Equipment

After the economic analysis and intangible factors analysis have been made, the problem of choosing the best equipment arises. The choice of the best equipment depends mainly on the translation of the figures obtained from the intangible factors analysis into dollars. This can be accomplished in two ways:

1. The trade-off between economic and intangible factors is left totally to the materials handling engineer.

2. The construction of an indifference curve (using utility theory). This can be accomplished by the use of questionnaires, interviews, and the like. This method is expensive and time consuming and usually does not pay off unless the equipment is very expensive.

The construction of indifference curves (6), (8), uses the experience of many people to trade off between economic and intangible factors. So both methods 1 and 2 are essentially the same, with the emphasis that method 1 benefits from the materials handling engineer experience, while method 2 benefits from many other's experience.

As an example, if we have equipment types A, B, C, D, E, and F, the equivalent annual cost, and the rating factors of which are shown in Figure 19, then equipment type B is chosen as the best. This is due to the fact that the lowest curve parallel to the indifference curve passes through the point B.

Conclusion

It should be noted that the outline given throughout this chapter represents an approach to be followed in the selection of materials handling equipment. This approach organizes the way of thinking, and instead of dealing with so many possible solutions, it reduces the possible solutions by using the levels of mechanization notion.

This method, though it helps the materials handling engineer, still requires his experience, evaluation and deep insight.

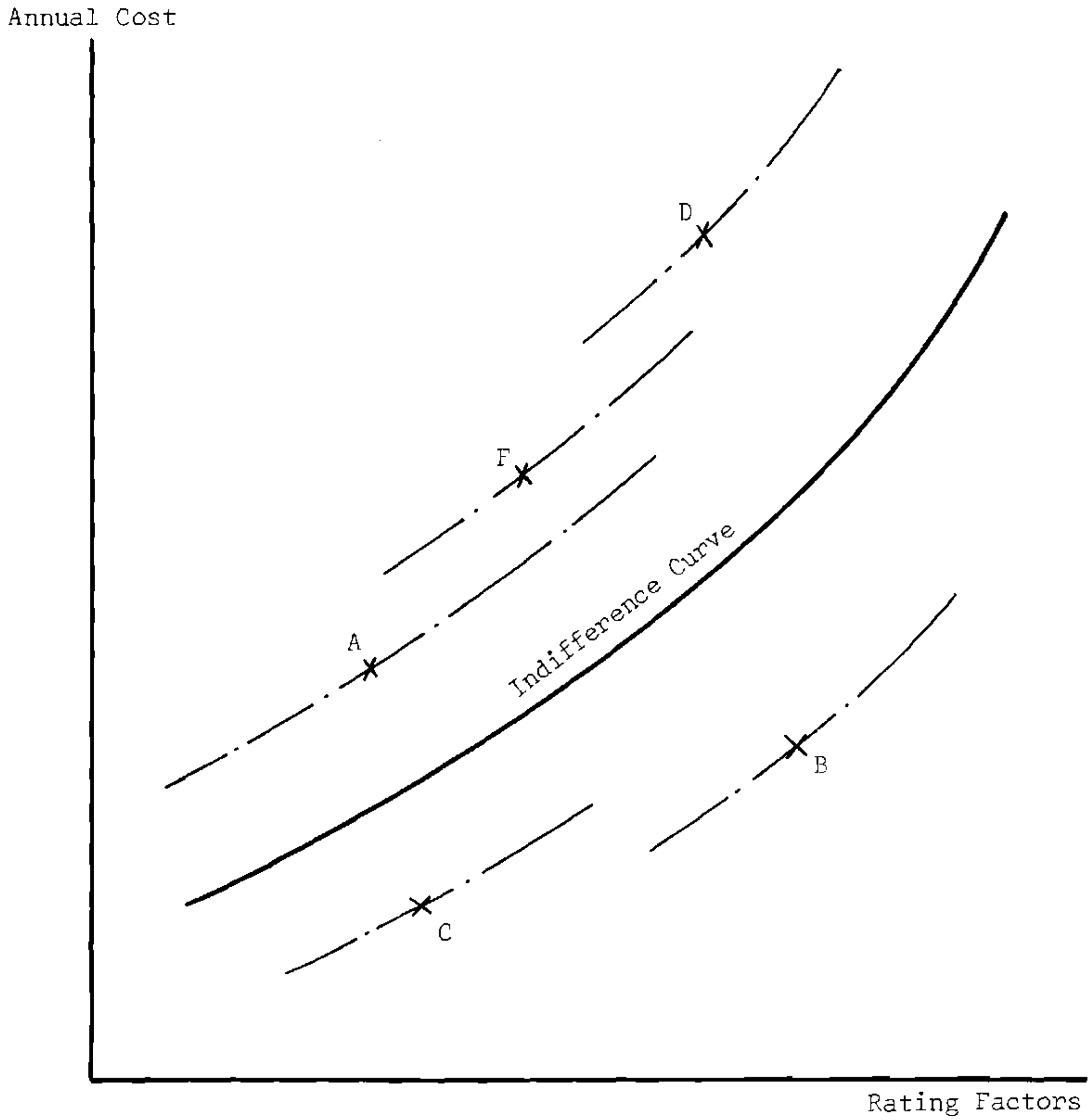


Figure 19. An Indifference Curve

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached as a result of developing this thesis:

1. Different materials handling activities have tendencies to be mechanized to varying degrees.

2. The appropriate level of mechanization depends upon relevant factors, such as the quantity being handled, the unit weight, the distance, the path, the frequency, and the speed.

3. There is an optimum level of mechanization corresponding to each handling operation. At this level the handling cost is a minimum.

4. A single level or a set of levels of mechanization can be assigned to each type of materials handling equipment.

5. The final selection of materials handling equipment is made after the selection of the proper degree of mechanization, on the basis of economic and intangible factors analysis.

The following recommendations are outlined for further research:

1. Developing a model for assigning a degree or degrees of mechanization according to the factors considered (quantity, speed, path, etc.).

2. Developing a model which will relate the handling cost per piece with the level of mechanization.

3. Deeper investigation of how to relate the cost factors to the intangible factors.

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